Indiana Academic Standards

Science

Chemistry

K-12 Science Indiana Academic Standards Overview

The K-12 Science Indiana Academic Standards are based on *A Framework for K-12 Science Education* (NRC 2012) and are meant to reflect a new vision for science education. The following conceptual shifts reflect what is new about these science standards. The K-12 Science Indiana Academic Standards

- reflect science as it is practiced and experienced in the real world,
- build logically from Kindergarten through Grade 12,
- focus on deeper understanding as well as application of content,
- integrate practices, crosscutting concepts, and core ideas.

The K-12 Science Indiana Academic Standards outline the knowledge and science and engineering practices that all students should learn by the end of high school. The standards are three-dimensional because each student performance expectation engages students at the nexus of the following three dimensions:

- Dimension 1 describes scientific and engineering practices.
- Dimension 2 describes crosscutting concepts, overarching science concepts that apply across science disciplines.
- Dimension 3 describes core ideas in the science disciplines.

Science and Engineering Practices

The eight practices describe what scientists use to investigate and build models and theories of the world around them or that engineers use as they build and design systems. The practices are essential for all students to learn and are as follows:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting Concepts

The seven crosscutting concepts bridge disciplinary boundaries and unit core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas, and develop a coherent, and scientifically based view of the world. The seven crosscutting concepts are as follows:

1. *Patterns*- Observed patterns of forms and events guide organization and classification, and prompt questions about relationships and the factors that influence them.
2. *Cause and effect- Mechanism and explanation*. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

3. *Scale, proportion, and quantity*- In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
4. *Systems and system models*- Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. *Energy and matter: Flows, cycles, and conservation*- Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. *Structure and function*- The way in which an object or living thing is shaped and its substructure determines many of its properties and functions.
7. *Stability and change*- For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Disciplinary Core Ideas
The disciplinary core ideas describe the content that occurs at each grade or course. The K-12 Science Indiana Academic Standards focus on a limited number of core ideas in science and engineering both within and across the disciplines and are built on the notion of learning as a developmental progression. The Disciplinary Core Ideas are grouped into the following domains:

- Physical Science (PS)
- Life Science (LS)
- Earth and Space Science (ESS)
- Engineering, Technology and Applications of Science (ETS)

The K-12 Science Indiana Academic Standards are not intended to be used as curriculum. Instead, the standards are the minimum that students should know and be able to do. Therefore, teachers should continue to differentiate for the needs of their students by adding depth and additional rigor.

Why use the Framework for K12 Science Education as the basis for the revision of science Indiana Academic Standards?

- The framework and standards are based on a rich and growing body of research on teaching and learning in science, as well as on nearly two decades of efforts to define foundational knowledge and skills for K-12 science and engineering.
- Studies show that even young children are naturally inquisitive and much more capable of abstract reasoning than previously thought. This means we can introduce elements of inquiry and explanation much earlier in the curriculum to help them develop deeper understanding.
- The new standards aim to eliminate the practice of “teaching to the test.” Instead, they shift the focus from merely memorizing scientific facts to actually doing science—so students spend more time posing questions and discovering the answers for themselves.
- Historically, K-12 instruction has encouraged students to master lots of facts that fall under “science” categories, but research shows that engaging in the practices used by scientists and engineers plays a critical role in comprehension. Teaching science as a process of inquiry and explanation helps students think past the subject matter and form a deeper understanding of how science applies broadly to everyday life. This is in alignment with the Indiana Priorities for STEM education.
- These new standards support the research by emphasizing a smaller number of core ideas that students can build on from grade to grade. The more manageable scope allows teachers to weave in practices and concepts common to all scientific disciplines — which better reflects the way students learn.
- It is important that each standard be presented in the 3-dimensional format to reflect its scope and full intent.
- Given that each standard is a performance expectation (what students should know and be able to do), the standards are presented with some accompanying supports including clarification and evidence statements.

How to read the revised Science Indiana Academic Standards

Standard Number	**Title**	The title for a set of performance expectations is not necessarily unique and may be reused at several different grade levels

Students who demonstrate understanding can:

Standard Number **Performance Expectation: A statement that combines practices, core ideas, and crosscutting concepts together to describe how students can show what they have learned** [Clarification Statement: A statement that supplies examples or additional clarification to the performance expectation.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Activities that scientists and engineers engage in to either understand the world or solve the problem. There are 8 practices. These are integrated into each standard. They were previously found at the beginning of each grade level content standard and known as SEPs. **Connections to the Nature of Science** Connections are listed in either practices or the crosscutting concepts section.	Concepts in science and engineering that have broad importance within and across disciplines as well as relevance in people's lives To be considered core, the ideas should meet at least two of the following criteria and ideally all four: • Have broad importance across multiple sciences or engineering disciplines or be a key organizing concept of a single discipline; • Provide a key tool for understanding or investigating more complex ideas and solving problems; • Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge; • Be teachable and learnable over multiple grades at increasing levels of depth and sophistication. Disciplinary ideas are grouped in four domains: the physical sciences; the life sciences; the earth and space sciences; and engineering, technology and applications of science.	Seven ideas such as Patterns and Cause and Effect, which are not specific to any one discipline but cut across them all. Crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas. **Connections to Engineering, Technology and Applications of Science** These connections are drawn from either the Disciplinary Core Ideas and Science and Engineering Practices.

Evidence Statements	
1	Evidence Statements provide educators with additional detail on what students should know and be able to do.
2	The evidence statements can be used to inform the scaffolding of instruction and the development of assessments.

HS-CHE1-1 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-1. **Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.** **[Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.]**

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ● Use a model to predict the relationships between systems or between components of a system.	**PS1.A: Structure and Properties of Matter** ● Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. ● The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.	**Patterns** ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Scaffolding necessary to meet performance expectation of the Standard

1. Develop problem-solving strategies used to determine the number of protons, neutrons, and electrons in an atom versus an isotope and to calculate the average atomic mass of chemical elements from isotopic abundance data.
2. Construct a model of an atom based on current understanding of the properties of subatomic particles and knowledge of isotopes.
3. Apply the knowledge of electron configurations within an element to relate to its position on the Periodic Table to its chemical and physical properties.

Observable features of the student performance by the end of the course:

1	Components of the model		
	a	From the given model, students identify and describe* the components of the model that are relevant for their predictions, including:	
		i.	Elements and their arrangement in the periodic table;
		ii.	A positively-charged nucleus composed of both protons and neutrons, surrounded by negatively-charged electrons;
		iii.	Electrons in the outermost energy level of atoms (i.e., valence electrons); and
		iv.	The number of protons in each element.
2	Relationships		
	a	Students identify and describe* the following relationships between components in the given model, including:	
		i.	The arrangement of the main groups of the periodic table reflects the patterns of outermost electrons.
		ii.	Elements in the periodic table are arranged by the numbers of protons in atoms.

3	Connections		
	a	Students use the periodic table to predict the patterns of behavior of the elements based on the attraction and repulsion between electrically charged particles and the patterns of outermost electrons that determine the typical reactivity of an atom.	
	b	Students predict the following patterns of properties:	
		i.	The number and types of bonds formed (i.e., ionic, covalent, metallic) by an element and between elements;
		ii.	The number and charges in stable ions that form from atoms in a group of the periodic table;
		iii.	The trend in reactivity and electronegativity of atoms down a group, and across a row in the periodic table, based on attractions of outermost (valence) electrons to the nucleus; and
		iv.	The relative sizes of atoms both across a row and down a group in the periodic table.

HS-CHE1-2 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-2. **Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.** [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ● Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**PS1.A: Structure and Properties of Matter** ● The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. **PS1.B: Chemical Reactions** ● The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Patterns** ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Scaffolding necessary to meet performance expectation of the Standard

1. Analyze the chemical and physical properties of substances to determine their identities.
2. Recognize indicators of both chemical and physical changes.
3. Construct models that represent the phases of matter and changes in state at the macroscopic and microscopic levels.
4. Investigate the physical properties of compounds then predict and identify them as being ionic or molecular compounds.
5. Compare and contrast ionic and covalent (molecular) bonding and ionic and molecular compounds.
6. Construct structural formulas for simple molecules and identify their molecular shape.
7. Determine the chemical formulas for ionic and covalent compounds when given the IUPAC names and how to name them when given chemical formulas.
8. Describe, classify, and give examples of various kinds of reactions: synthesis (i.e., combination), decomposition, single displacement, double displacement, acid/base, and combustion.
9. Predict products of simple reactions and relate their reactivity to trends observed in the Periodic Table.
10. Balance chemical equations using the law of conservation of mass.

Observable features of the student performance by the end of the course:

1	Articulating the explanation of phenomena	
	a	Students construct an explanation of the outcome of the given reaction, including:
		i. The idea that the total number of atoms of each element in the reactant and products is the same;

		ii. The numbers and types of bonds (i.e., ionic, covalent) that each atom forms, as determined by the outermost (valence) electron states and the electronegativity;
		iii. The outermost (valence) electron state of the atoms that make up both the reactants and the products of the reaction is based on their position in the periodic table; and
		iv. A discussion of how the patterns of attraction allow the prediction of the type of reaction that occurs (e.g., formation of ionic compounds, combustion of hydrocarbons).
2	Evidence	
	a	Students identify and describe* the evidence to construct the explanation, including:
		i. Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons;
		ii. Identification that the number and types of atoms are the same both before and after a reaction;
		iii. Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products;
		iv. The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic level as determined by using the periodic table; and
		v. The outermost (valence) electron configuration and the relative electronegativity of the atoms that make up both the reactants and the products of the reaction based on their position in the periodic table.
3	Reasoning	
	a	Students describe* their reasoning that connects the evidence, along with the assumption that theories and laws that describe their natural world operate today as they did in the past and will continue to do so in the future, to construct an explanation for how the patterns of outermost electrons and the electronegativity of elements can be used to predict the number and types of bonds each element forms.
	b	In the explanation, students describe* the causal relationship between the observable macroscopic patterns of reactivity of elements in the periodic table and the patterns of outermost electrons for each atom and its relative electronegativity.
4	Revising the explanation	
	a	Given new evidence or context, students construct a revised or expanded explanation about the outcome of a chemical reaction and justify the revision.

HS-CHE1-3 Matter and its Interactions		
Students who demonstrate understanding can: **HS-CHE1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.** [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension]		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	**PS1.A: Structure and Properties of Matter** • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Scaffolding necessary to meet performance expectation of the Standard		
Compare and contrast ionic, covalent, network, metallic, polar, and non-polar substances with respect to constituent particles, strength of bonds, melting, and boiling points and conductivity; provide examples of each type.		
Observable features of the student performance by the end of the course:		
1	Identifying the phenomenon to be investigated	
	a	Students describe* the phenomenon under investigation, which includes the following idea: the relationship between the measurable properties (e.g., melting point, boiling point, vapor pressure, surface tension) of a substance and the strength of the electrical forces between the particles of the substance.
2	Identifying the evidence to answer this question	
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including bulk properties of a substance (e.g., melting point and boiling point, volatility, surface tension) that would allow inferences to be made about the strength of electrical forces between particles.
	b	Students describe* why the data about bulk properties would provide information about strength of the electrical forces between the particles of the chosen substances, including the following descriptions*:
		i. The spacing of the particles of the chosen substances can change as a result of the experimental procedure even if the identity of the particles does not change (e.g., when water is boiled the molecules are still present but further apart).
		ii. Thermal (kinetic) energy has an effect on the ability of the electrical attraction between particles to keep the particles close together. Thus, as more energy is added to the

			system, the forces of attraction between the particles can no longer keep the particles close together.
		iii.	The patterns of interactions between particles at the molecular scale are reflected in the patterns of behavior at the macroscopic scale.
		iv.	Together, patterns observed at multiple scales can provide evidence of the causal relationships between the strength of the electrical forces between particles and the structure of substances at the bulk scale.
3	Planning for the investigation		
	a	In the investigation plan, students include:	
		i.	A rationale for the choice of substances to compare and a description* of the composition of those substances at the atomic molecular scale.
		ii.	A description* of how the data will be collected, the number of trials, and the experimental set up and equipment required.
	b	Students describe* how the data will be collected, the number of trials, the experimental set up, and the equipment required.	
4	Collecting the data		
	a	Students collect and record data — quantitative and/or qualitative — on the bulk properties of substances.	
5	Refining the design		
	a	Students evaluate their investigation, including evaluation of:	
		i.	Assessing the accuracy and precision of the data collected, as well as the limitations of the investigation; and
		ii.	The ability of the data to provide the evidence required.
	b	If necessary, students refine the plan to produce more accurate, precise, and useful data.	

HS-CHE1-4 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-4. **Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.** [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.]

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.

PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

Crosscutting Concepts

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Scaffolding necessary to meet performance expectation of the Standard

1. Explain that atoms and molecules are in constant motion and that this motion increases as thermal energy increases.
2. Distinguish between the concepts of temperature and heat flow in macroscopic and microscopic terms.

Observable features of the student performance by the end of the course:

1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe* the relevant components, including:	
		i.	The chemical reaction, the system, and the surroundings under study;
		ii.	The bonds that are broken during the course of the reaction;
		iii.	The bonds that are formed during the course of the reaction;
		iv.	The energy transfer between the systems and their components or the system and surroundings;
		v.	The transformation of potential energy from the chemical system interactions to kinetic energy in the surroundings (or vice versa) by molecular collisions; and
		vi.	The relative potential energies of the reactants and the products.
2	Relationships		

	a	In the model, students include and describe* the relationships between components, including:	
		i.	The net change of energy within the system is the result of bonds that are broken and formed during the reaction (Note: This does not include calculating the total bond energy changes.);
		ii.	The energy transfer between system and surroundings by molecular collisions;
		iii.	The total energy change of the chemical reaction system is matched by an equal but opposite change of energy in the surroundings (Note: This does not include calculating the total bond energy changes.); and
		iv.	The release or absorption of energy depends on whether the relative potential energies of the reactants and products decrease or increase.
3	Connections		
	a	Students use the developed model to illustrate:	
		i.	The energy change within the system is accounted for by the change in the bond energies of the reactants and products. (Note: This does not include calculating the total bond energy changes.)
		ii.	Breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings.
		iii.	The energy transfer between systems and surroundings is the difference in energy between the bond energies of the reactants and the products.
		iv.	The overall energy of the system and surroundings is unchanged (conserved) during the reaction.
		v.	Energy transfer occurs during molecular collisions.
		vi.	The relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.

Possible extensions in learning

1. Use enthalpy values to classify chemical reactions and phase changes as exothermic or endothermic.
2. Perform calculations involving heat flow, temperature changes, and phase changes by using known values of specific heat, phase change constants, or both.
3. Use the kinetic molecular theory with the combined and ideal gas laws to explain changes in volume, pressure, moles, and temperature of a gas,

HS-CHE1-5 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ● Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.	**PS1.B: Chemical Reactions** ● Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.	**Patterns** ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes the idea that as the kinetic energy of colliding particles increases and the number of collisions increases, the reaction rate increases.	
2	Evidence		
	a	Students identify and describe* evidence to construct the explanation, including:	
		i.	Evidence (e.g., from a table of data) of a pattern that increases in concentration (e.g., a change in one concentration while the other concentration is held constant) increase the reaction rate, and vice versa; and
		ii.	Evidence of a pattern that increases in temperature usually increases the reaction rate, and vice versa.
3	Reasoning		
	a	Students use and describe* the following chain of reasoning that integrates evidence, facts, and scientific principles to construct the explanation:	
		i.	Molecules that collide can break bonds and form new bonds, producing new molecules.
		ii.	The probability of bonds breaking in the collision depends on the kinetic energy of the collision being sufficient to break the bond, since bond breaking requires energy.
		iii.	Since temperature is a measure of average kinetic energy, a higher temperature means that molecular collisions will, on average, be more likely to break bonds and form new bonds.
		iv.	At a fixed concentration, molecules that are moving faster also collide more frequently, so molecules with higher kinetic energy are likely to collide more often.
		v.	A high concentration means that there are more molecules in a given volume and thus more particle collisions per unit of time at the same temperature.

HS-CHE1-6 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-6. **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**PS1.B: Chemical Reactions** • In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary)*	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable.

Scaffolding necessary to meet performance expectation of the Standard

1. Use a balanced chemical equation to calculate the quantities of reactants needed and products made in a chemical reaction that goes to completion.
2. Describe the composition and properties of solutions.
3. Explain how temperature, pressure, and polarity of the solvent affect the solubility of a solute.

Observable features of the student performance by the end of the course:

1	Using scientific knowledge to generate the design solution		
	a	Students identify and describe* potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe* the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including:	
		i.	How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components;
		ii.	That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal; and
		iii.	A description* of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level.
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe* the prioritized criteria and constraints and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources.
3	Evaluating potential solutions	
	a	Students systematically evaluate the proposed refinements to the design of the given chemical system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
4	Refining and/or optimizing the design solution	
	a	Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product and describe* the reasoning behind design decisions.

HS-CHE1-7 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-7. **Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.** [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.]

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to support claims.

Disciplinary Core Ideas

PS1.B: Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscutting Concepts

Energy and Matter

- The total amount of energy and matter in closed systems is conserved.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify and describe* the relevant components in the mathematical representations:	
		i.	Quantities of reactants and products of a chemical reaction in terms of atoms, moles, and mass;
		ii.	Molar mass of all components of the reaction;
		iii.	Use of balanced chemical equation(s); and
		iv.	Identification of the claim that atoms, and therefore mass, are conserved during a chemical reaction.
	b	The mathematical representations may include numerical calculations, graphs, or other pictorial depictions of quantitative information.	
	c	Students identify the claim to be supported: that atoms, and therefore mass, are conserved during a chemical reaction.	
2	Mathematical modeling		
	a	Students use the mole to convert between the atomic and macroscopic scale in the analysis.	
	b	Given a chemical reaction, students use the mathematical representations to	
		i.	Predict the relative number of atoms in the reactants versus the products at the atomic molecular scale; and
		ii.	Calculate the mass of any component of a reaction, given any other component.
3	Analysis		

	a	Students describe* how the mathematical representations (e.g., stoichiometric calculations to show that the number of atoms or number of moles is unchanged after a chemical reaction where a specific mass of reactant is converted to product) support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
	b	Students describe* how the mass of a substance can be used to determine the number of atoms, molecules, or ions using moles and mole relationships (e.g., macroscopic to atomic molecular scale conversion using the number of moles and Avogadro's number).

HS-CHE1-8 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-8. Use mathematical representations to describe the composition and properties of individual solutions and solutions involved in chemical reactions.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena to support claims.	**PS1.B: Chemical Reactions** • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Energy and Matter** • The total amount of energy and matter in closed systems is conserved. - ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** • Science assumes the universe is a vast single system in which basic laws are consistent.

Scaffolding necessary to meet performance expectation of the Standard

1. Describe the composition and properties of solutions.
2. Explain how temperature, pressure, and polarity of the solvent affect the solubility of a solute.
3. Describe the concentration of solutes in a solution in terms of molarity.
4. Perform calculations using molarity, mass, and volume. Prepare a sample of given molarity provided a known solute.
5. Classify solutions as acids or bases and describe their characteristic properties.
6. Compare and contrast the strength of acids and bases in solutions.
7. Given the hydronium ion and/or the hydroxide ion concentration, calculate the pH and/or the pOH of a solution. Explain the meanings of these values.

HS-CHE1-9 Matter and its Interactions

Students who demonstrate understanding can:

HS-CHE1-9. **Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.** [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.]

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.

Crosscutting Concepts

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Observable features of the student performance by the end of the course:		
1	Components of the model	
	a	Students develop models in which they identify and describe* the relevant components of the models, including:
		i. Identification of an element by the number of protons;
		ii. The number of protons and neutrons in the nucleus before and after the decay;
		iii. The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and
		iv. The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.
2	Relationships	
	a	Students develop five distinct models to illustrate the relationships between components underlying the nuclear processes of 1) fission, 2) fusion and 3) three distinct types of radioactive decay.
	b	Students include the following features, based on evidence, in all five models:
		i. The total number of neutrons plus protons is the same both before and after the nuclear process, although the total number of protons and the total number of neutrons may be different before and after.
		ii. The scale of energy changes in a nuclear process is much larger (hundreds of thousands or even millions of times larger) than the scale of energy changes in a chemical process.
3	Connections	
	a	Students develop a fusion model that illustrates a process in which two nuclei merge to form a single, larger nucleus with a larger number of protons than were in either of the two original nuclei.

	b	Students develop a fission model that illustrates a process in which a nucleus splits into two or more fragments that each have a smaller number of protons than were in the original nucleus.
	c	In both the fission and fusion models, students illustrate that these processes may release energy and may require initial energy for the reaction to take place.
	d	Students develop radioactive decay models that illustrate the differences in type of energy (e.g., kinetic energy, electromagnetic radiation) and type of particle (e.g., alpha particle, beta particle) released during alpha, beta, and gamma radioactive decay, and any change from one element to another that can occur due to the process.
	e	Students develop radioactive decay models that describe* that alpha particle emission is a type of fission reaction, and that beta and gamma emission are not.

HS-CHE3-1 Energy

Students who demonstrate understanding can:

HS-CHE3-1. **Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.]

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.

Crosscutting Concepts

Systems and System Models

- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent.

Scaffolding necessary to meet the performance expectation of the standard

1. Distinguish between the concepts of temperature and heat flow in macroscopic and microscopic terms.
2. Classify chemical reactions and phase changes as exothermic or endothermic based on enthalpy values. Use a graphical representation to illustrate the energy changes involved.
3. Perform calculations involving heat flow, temperature changes, and phase changes by using known values of specific heat, phase change constants, or both.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students identify and describe* the components to be computationally modeled, including: v. The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero); vi. The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system; vii. The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and viii. The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.
2	Computational Modeling	
	a	Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
	b	Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.
3	Analysis	
	a	Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
	b	Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

HS-CHE3-2 Energy

Students who demonstrate understanding can:

HS-CHE3-2. **Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).** [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ● Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	**PS3.A: Definitions of Energy** ● Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. ● At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. ● These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**Energy and Matter** ● Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models in which they identify and describe* the relevant components, including:	
		i.	All the components of the system and the surroundings, as well as energy flows between the system and the surroundings;

		ii. Clearly depicting both a macroscopic and a molecular/atomic-level representation of the system; and
		iii. Depicting the forms in which energy is manifested at two different scales:
		a) Macroscopic, such as motion, sound, light, thermal energy, potential energy or energy in fields; and
		b) Molecular/atomic, such as motions (kinetic energy) of particles (e.g., nuclei and electrons), the relative positions of particles in fields (potential energy), and energy in fields.
2	Relationships	
	a	Students describe* the relationships between components in their models, including:
		i. Changes in the relative position of objects in gravitational, magnetic or electrostatic fields can affect the energy of the fields (e.g., charged objects moving away from each other change the field energy).
		ii. Thermal energy includes both the kinetic and potential energy of particle vibrations in solids or molecules and the kinetic energy of freely moving particles (e.g., inert gas atoms, molecules) in liquids and gases.
		iii. The total energy of the system and surroundings is conserved at a macroscopic and molecular/atomic level.
		iv. As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields.
3	Connections	
	a	Students use their models to show that in closed systems the energy is conserved on both the macroscopic and molecular/atomic scales so that as one form of energy changes, the total system energy remains constant, as evidenced by the other forms of energy changing by the same amount or changes only by the amount of energy that is transferred into or out of the system.
	b	Students use their models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles/objects and energy associated with the relative positions of particles/objects on both the macroscopic and microscopic scales.

HS-CHE3-3 Energy

Students who demonstrate understanding can:

HS-PS3-3. **Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	**PS3.B: Conservation of Energy and Energy Transfer** ● Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. ● Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). **PS3.D: Energy in Chemical Processes** ● Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.	**Systems and System Models** ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe* the purpose of the investigation, which includes the following idea, that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including:	
		i.	The measurement of the reduction of temperature of the hot object and the increase in temperature of the cold object to show that the thermal energy lost by the hot object is equal to the thermal energy gained by the cold object and that the distribution of thermal energy is more uniform after the interaction of the hot and cold components; and
		ii.	The heat capacity of the components in the system (obtained from scientific literature).
3	Planning for the investigation		
	a	In the investigation plan, students describe*:	

		i. How a nearly closed system will be constructed, including the boundaries and initial conditions of the system;
		ii. The data that will be collected, including masses of components and initial and final temperatures; and
		iii. The experimental procedure, including how the data will be collected, the number of trials, the experimental setup, and equipment required.
4	Collecting the data	
	a	Students collect and record data that can be used to calculate the change in thermal energy of each of the two components of the system.
5	Refining the design	
	a	Students evaluate their investigation, including:
		i. The accuracy and precision of the data collected, as well as the limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the plan to produce more accurate, precise, and useful data that address the experimental question.
	c	Students identify potential causes of the apparent loss of energy from a closed system (which should be zero in an ideal system) and adjust the design of the experiment accordingly.